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Performance Studies of Keewatin Channel Bridge

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Performance Studies of Keewatin Channel Bridge

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Abstract: This report describes the structural evaluation and load test study performed on Keewatin Channel Bridge. The bridge is a three pin arch structure with 104.0 m span. The structural evaluation under OHBDC Level 3 live loads and including the increased dead loads to accomodate a proposed rehabilitation scheme indicated that selected truss top chords, verticals and diagonals require strengthening.

The test results showed that none of the above members require strengthening to carry out the proposed rehabilitation work and to carry OHBDC loads without posting.

Key Words: testing, evaluation, Keewatin Channel Bridge, performance study, load testing

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1/ INTRODUCTION

The Keewatin Channel Bridge is located on Hwy 17 (the Trans-Canada Highway) near Kenora, in north-western Ontario. A view of the bridge is shown in Figure 1. The bridge is a major structure with reinforced concrete approach spans totalling a length of approximately 169.0 m with a centre span of steel three-pin arch truss approximately 104.0 m long.

A bridge inspection survey was conducted by consulting engineers Wyllie and Ufnal Ltd. [1] in July 1984. They inspected the approach spans in sufficient detail to aid preparation of a rehabilitation contract. They also conducted a survey of the deck area covering the approach spans and the centre steel truss span. Only cursory inspections were conducted on the centre steel truss members.

Although the reinforced concrete approach spans showed some severe localized deterioration, mostly at expansion joints, the structure did not exhibit visual signs of overload distress. The top surface of the concrete deck covering the steel truss span showed very high corrosion potential and high chloride content and the MTC Structural Office evaluated the various alternative available to upgrade this portion of the deck. Details of the final rehabilitation proposals are as follows:

- Scarify by 25 mm the existing 150 mm deck, including the sidewalk.
- Add a 45 mm concrete overlay to the deck slab.
- Overlay existing sidewalk with 30 mm concrete.
- Waterproof and add 90 mm of asphalt.
- Retain existing parapet wall.

Structural evaluation based on the above proposals and for Level 3 OHBDC live loads showed that:

1/ The floor system has adequate capacity except for the truss top chord. This acts as an end stringer and its capacity is exceeded under combined axial compression and bending, but not bending alone.

2/ The truss top chords also have adequate capacity to sustain axial forces alone, as developed by truss action.

3/ All other truss members have adequate member resistance except for some vertical and diagonal members.

Strengthening the truss members can be a costly exercise because they are generally built-up sections, fabricated using steel angles, plates and reverted steel connections.

In the past, load tests have shown that the actual member forces induced are generally lower than those obtained by analytical methods. The bridge was therefore load tested to study its characteristics under applied test truck loads. Because of its long span, the truss could not be loaded with MTC trucks to produce forces in the truss members equivalent to OHBDC Level 3 loads. However, it is felt that the truss member behaviour observed under test truck loads can be utilized to assess the adequacy of members under ultimate OHBDC Level 3 loads.

This report present the results of the structural evaluation and load testing studies performed on the steel arch structure of the Keewatin Channel Bridge. As the deteriorated areas of the approach spans are rehabilitated and structurally adequate to sustain the extra dead loads involved, these are not included in the present study.

2/ BRIDGE DETAILS

The Keewatin Channel Bridge was built in 1938 and was designed for Class H 20 loads. The west approach spans comprise 13.72, 29.26, and 29.26 m structures and the east approach spans comprise 8.30, 16.64, 16.64, and 25.90 m structures. Both approach spans were constructed of reinforced concrete.

The centre steel three-pin arch structure spans 104.1 m between end hinges and has a rise of 13.18 m. Details of the truss bridge are given in Figure 2. The bridge has a two-lane roadway of total width 9.14 m and a sidewalk 1.42 m wide on the south side. The roadway and sidewalk deck comprise a 150 mm deep concrete slab. The roadway slab has 75 mm asphalt topping without waterproofing membrane but the sidewalk remains exposed.

The roadway slab is supported by three internal stringers and two outer stringers which also act as the top chord of the truss. The stringers are placed at 2.23 m centres. The stringers have two span lengths, a span of 4.67 m for deck panels adjacent to the centre hinge (6 panels), and a span of 7.08 m at either end of the bridge (10 panels). The stringers are sections built-up using angles, plates and rivetted connections; the internal stringers are of I-beam type; and the outer stringers/top chord are of box type with lacings on the bottom face.

The floor beams are connected to the top chords of the truss at the nodal points. The floor beams are also sections built-up using angles, plates and rivetted connections and are of I-beam type. The floor beams span between the two trusses except at nodes U_4 to U_8 and for those nodes symmetrically opposite where sway bracings are framed into the beams at their midspan locations (see also Figure 2). Between the floor beams there are W250 x 45 kg/m steel beam diaphragms placed at 2.36 m centres. The truss members comprise sections built up using angles, plates, riverted connections and with or without lacings.

The truss members, stringers, floor beams and diaphragms are in very good condition. The road deck and the sidewalk showed high corrosion potential values and/or high chloride content. The underside of the deck is in good condition except in few locations where the reinforcement on the underside has corroded severely. For additional details on the bridge deck condition see Reference 1, the condition survey report prepared by Wyllie and Ufnal Ltd.

3/ BRIDGE EVALUATION

The bridge was evaluated according to the OHBDC [2] considering loadings at Ultimate Level 3. The dead loads on the structure were calculated for the proposed deck rehabilitation program mentioned previously in Chapter 1. The evaluation calculations were performed only on the main structural members, and no attempt was made to evaluate secondary members and/or connections.

The deck slab was evaluated using the empirical method described in the OHBDC [2] and gave a factored capacity of 200 kN compared to a factored load of 196 kN. The slab thickness considered for the above resistance calculation was 150 mm. The use of 170 mm for the rehabilitated deck would increase the safety margin. Because the steel girder diaphragms are placed at 2.36 m centres, almost equal to stringer spacing, the deck may act as a two-way slab, thus enhancing the load capacity. The load capacity evaluated using the OHBDC empirical formulae does not account for the possible two-way action in the deck.

The applied midspan moments and their corresponding moment of resistance values for the stringers and the floor beams are given in Table 1. The interior stringers carry only the flexural loads while the exterior stringers (being also the truss top chord) carry both flexural and axial loads. The effects of the combined axial and flexural loads are presented in Table 2(c) and discussed later. However, the interior stringers have moment capacity in excess of that required, and for flexural loads alone the exterior stringers also have adequate capacity.

The floor beam moment of resistance, calculated considering the beams as a compact section with continuous lateral restraint for the compression flange, showed the beams to have adequate capacity. Possible reductions in the applied moment feasible due to the propping action of bracings attached to some of the floor beams are not accounted for in the present calculations.

The maximum forces induced on the truss members by the OHBDC Level 3 loads and the corresponding member resistance values are given in Table 2(a) and 2(b). The combined effects of axial loads and bending moments are illustrated in Table 2(c). As evident from Table 2(a) and 2(b), all

the truss members (except for some vertical and diagonal members) have the necessary strength to sustain the applied loads. However, for the top chords, U_3U_4 and U_4U_5, the combined axial load and bending moment exceeds the section capacity (see Table 2(c)).

4/ INSTRUMENTATION AND TESTING

The truss structure is very large and in order to economize on the number of gauges used, only selected members on one arm of the three-pin arch truss were instrumented. In total, 56 gauges were used, comprising both weldable and demountable type strain gauges. The displacement on the truss due to the applied loads was not measured due to practical difficulties introduced by the height of the structure and/or the depth of water below the bridge. The instrumentation details are given in Figure 3(a).

The test truck positions were determined to achieve the maximum induced loads on the critical members and to keep the total number of test load cases to a practicable level. The test truck loads and the truck positions used during the test are summarized in Figure 3(b).

5/ TEST RESULTS

5.1/ Stringers

The measured strains on the stringers in the panel U_1U_2 under various load levels and the truck lines Line 4 and Line 5 are given in Table 3. The truck longitudinal position is Position 2. The test results indicate compressive strains are lower than the tensile strains except for Stringer #4. However, the results suggest that the stringers act partially compositely with the concrete deck. The end stringer/truss top chord exhibited much lower strains than the interior girders. This may be due to:

1/ a lesser portion of the total load being shared by the end stringers, and

2/ these stringers being relatively stiffer than the interior girders.

The measured stringer strains and the corresponding calculated strains are plotted in Figure 4 for load Levels 4 and 5 and truck Load Lines 4 and 5. For the end stringers/top chord, the strains are calculated allowing for the combined effect of axial forces and bending moments. Figure 4 clearly shows the following:

1/ The measured strains are very much lower than the calculated values, the reduction is greater for exterior stringers/top chord than for interior stringers.

2/ The stringers act partially compositely.

3/ The end stringer/top chord is much more highly sensitive to flexural loads than axial loads.

The third conclusion is arrived at noting that for loading cases where the axial load in the stringers are dominant, the measured strains indicate that the stringer is in flexure. This phenomenon may be due to the fact that the concrete deck and stringers can share the axial loads induced on the top chord. This aspect is usually ignored in calculating the theoretical strain value shown in Figure 4.

The structural evaluation of the stringers for OHBDC Load Level 3 showed that the internal stringers have adequate capacity, but the end stringers can fail under the combined effect of axial compression and bending moment. For the exterior stringers, the measured compressive strains at the top flange are about one-tenth of the calculated vales. The condition of combined axial compression and bending on the end stringer considered for the evaluation is not critical after all. As mentioned earlier, this is due to top chord forces being shared by the concrete deck and the stringers. Therefore both the exterior and interior stringers have adequate capacity to sustain OHBDC Level 3 loads.

5.2/ Floor Beams

The strains measured on the floor beam mid-span locations for various truck loading conditions are given in Tables 4 and 5. Table 4 presents the strains measured on each floor beam simultaneously for each truck position, while Table 5 shows the strains measured on each floor beam as the truck travelled along. Figure 5 shows the measured strains for load Level 5 and truck lines 4 and 5 plotted against truck position. The floor beam strains increase to a certain maximum strain value and then reduce as the truck traverses the deck. For floor beams at U1, U2, and U3 the maximum values are considerably higher than those at floor beams U4 or U5. The floor beam at U4 has marginally greater flexural rigidity than the floor beams U1 to U5. Floor beams U1 to U3 span freely between the truss top chords while the beams at U4 and U5 have bracings attached to them (see Figures 2 and 5). These bracings are not usually intended to contribute to floor beam stiffness, but are added to the structure for other considerations such as wind and/or transverse bracing of the truss. However, as seen from the test results, the floor beam strains are reduced to about one-fifth the strain values measured for floor beams U1 to U3.

The measured and calculated floor beam strains for load level 5 and truck load line 5 are given relative to truck position in Figure 6. As observed, the peak measured strains are lower than the calculated strains. For floor beams U1, U2, and U3 the measured strains are about

70 to 80% of calculated strains. For floor beams at U4 and U5, the reduction is very high and approximately 16% of the calculated strain. Although floor beams U4 and U5 have widely different type of bracings, the percentage difference between the measured and calculated strain values is approximately equal. Theoretical strain values obtained allowing for the stiffening effect of the bracings compare very well to the actual strain measurements. This suggests that for floor beam strength evaluations, the effect of the bracing in stiffening the beam can be taken into consideration without causing undue error in the evaluated capacities.

5.3/ Truss Members

The strains measured on truss members for Load Level 4, Load Level 5, and various truck positions are given in Table 6. The top chord members showed very low strain values. The bottom chord gave strains up to a maximum of 283 μs(56.6 MPa), while strains were recorded on the verticals up to a maximum of 413 μs(82.6 MPa). The diagonals gave the greatest strain values with a maximum recorded of 567 μs(113.4 MPa). The measured and calculated values of strains are compared in Table 7 for load Level 5, Line 4. For the top chords the measured strains are very low compared to the calculated values. As discussed earlier, the concrete deck and the steel stringers share the compressive loads induced on the top chord which gives rise to lower measured strain values. Although for bottom chords, measured strains at a few locations appear to be erroneous, the measured strains are reasonably close to the calculated values. Vertical member strains appear generally lower than the calculated strains and approximately 70 to 90% of the calculated values. In the case of the diagonals, the measured strains are lower than the calculated strains at approximately 60 to 80%.

The truss, top chord evaluation under OHBDC Level 3 loads showed that it can fail under combined axial compression and bending. As discussed earlier, the truss top chords carry considerably lower axial compression than calculated theoretically and hence it may be concluded that the top chord can sustain OHBDC Level 3 Loads. The truss bottom chords were shown to have the required strength and the test results confirm that these members do not show any form of distress or greater flexibility.

Evaluation of verticals showed that members U_1L_1 and U_2L_2 have marginally lower capacity than required, however, the lower observed strain measurements confirm that these members require no strengthening. The evaluation of the diagonals U_6L_7 and U_7L_8 showed that they require strengthening. As evident from the test results, which showed that the members recorded about 60 to 70% of the calculated strains, the diagonals require no strengthening. The test results therefore suggest that none of the truss members require strengthening.

The truss hinges at the end supports were inspected and they are in good condition. The hinges at the truss crown were not inspected. Salt water could have seeped through the joint above the hinges, causing accelerated corrosion activity. The hinge is a critical element for the functioning of the bridge trusses. It is therefore recommended that the hinges be inspected and repaired if warranted.

7/ CONCLUSIONS

The structural evaluation of the Keewatin Channel Bridge according to the procedures outlined in the OHBDC for Level 3 loads showed the following,

1/ The interior stringers have adequate strength to sustain OHBDC loads.

2/ The exterior stringer/truss top chord is able to sustain flexural loads; however, the section capacity is 31% below the strength required to sustain the combined effect of axial compression and bending moments.

3/ The floor beams have adequate capacity.

4/ The truss top chords are able to carry the compressive load, however failure may result under the combined effect of axial compression and flexure.

5/ The bottom chord has adequate capacity.

6/ Except for U_1L_1 and U_2L_2, the verticals have adequate capacity.

7/ All diagonals except U_6L_7 and U_7L_8 have the capacity to sustain OHBDC loads.

As a result of the test the following conclusions are deduced.

1/ The interior stringers have considerably higher stiffness/strength than predicted by evaluation.

2/ The effect of axial compression on the external stringer/top chord is minimized by the sharing of the axial loads between the top chord, the concrete deck, and/or the stringers. The axial load effect on the chord is so insignificant that its effect can be ignored. Test results, however, confirm that the top chord has adequate capacity to sustain OHBDC loads.

3/ The floor beams showed greater stiffness than predicted by evaluation.

4/ The measured top chord strains are considerably lower than the calculated strains. The axial compressive load induced on the top chord is shared by the concrete deck and the stringers and this renders the top chord insensitive to the induced axial loads. The test results confirm that the top chord has adequate capacity to sustain OHBDC Level 3 loads.

5/ The measured bottom chord strains are close to the calculated strains and confirm the evaluation finding that it has the required resistance.

6/ The measured strains on the verticals and diagonals are lower than the calculated strains. The test results suggest that the verticals and diagonal which failed to satisfy OHBDC Level 3 loads can safely carry these loads without strengthening.

8/ RECOMMENDATIONS

1/ The bridge requires no strengthening for any of its member to sustain OHBDC loads and the increase in dead load due to the proposed deck repair program.

2/ Due to safety considerations, the truss hinge at the centre of the truss should be inspected thoroughly and remedial repairs, if necessary, should be carried out.

REFERENCES

[1] Furst, PER., "Detailed Bridge Condition Survey, Kewatin Channel Bridge," Wyllie and Ufnal Ltd., July 1984.

[2] "Ontario Highway Bridge Design Code," Ministry of Transportation and Communications, Downsview, Ontario, 1983.

Table 1/ Factored Midspan Momements Compared to Factored Resistances for Stringers and Floor Beams

Members	Span (m)	Factored Midspan Moments (kNm)	Factored Resistances (kNm)
Interior Stringers	7.08	547.0	615.0
	4.67	350.0	409.0
Exterior Stringers	7.08	482.0	694.0
	4.67	290.0	694.0
Floor Beams			
@ U_0	--	1464.0	1863.0
U_1 to U_3	--	1861.0	1996.0
U_4	--	1861.0	2105.0
U_5	--	1641.0	1996.0
U_0 to U_7	--	1418.0	1863.0
U_8	--	1240.0	1729.0

Stringer dynamic load allowance = 0.25
Floor beam dynamic load allowance = 0.25
F_y = 230 MPa

Table 2(a)/ Truss Member Forces Related to Member Resistances

Member	Factored Axial Forces (kN)		Factored Axial Resistances (kN)	
	Comp.	Ten.	Comp.	Ten.
Top Chords				
U_0U_1	-757	244	-4182	4347
U_1U_2	-1302	848	-4182	4347
U_2U_3	-1930	1752	-4182	4347
U_3U_4	-2668	2550	-4182	4347
U_4U_5	-3423	3048	-4182	4347
U_5U_6	-3008	3178	-4341	4347
U_6U_7	-2704	1771	-4341	4347
Bottom Chords				
L_0L_1	-10121	0	-12150	13000
L_1L_2	-10146	100	-11985	12710
L_2L_3	-10152	339	-11793	12500
L_3L_4	-10640	715	-11832	12500
L_4L_5	-10887	1077	-11870	12500
L_5L_6	-11173	1233	-12420	12500
L_6L_7	-10851	925	-11911	12000
L_7L_8	-9411	146	-11565	11500

Dynamic Load Allowance for Truss Member = 0.25

Table 2(b)/ Truss Member Forces Related to Member Resistances

Member	Factored Axial Forces (kN)		Factored Axial Resistances (kN)	
	Comp.	Ten.	Comp.	Ten.
Vertical				
U_0L_0	-1347	472	-1681	1962
U_1L_1	-1834	32	-1703	1600
U_2L_2	-1770	13	-1717	1469
U_3L_3	-1259	182	-1623	1384
U_4L_4	-1141	129	-1467	1350
U_5L_5	-1022	119	-994	1305
U_6L_6	-642	351	-994	1305
U_7L_7	-798	398	-994	1305
Diagonals				
U_0L_1	-900	1038	-1075	1080
U_1L_2	-719	1249	-1360	1204
U_2L_3	-956	1029	-1620	1638
U_3L_4	-850	1248	-1675	1638
U_4L_5	-839	1288	-1704	1638
U_5L_6	-593	799	-1249	950
U_6L_7	-1481	1202	-1249	927
U_7L_8	-2161	2237	-1636	1257

Table 2(c)/ Combined Effect of Axial Forces and Bending Moments on The Top Chords

Member	Factored Fores		Factored Resistaces		$F = \left(\frac{C_f}{C_r} + \frac{M_f}{M_r}\right)$
	Axial (kN)	Moment (kNm)	Axial (kN)	Moment (kNm)	
Top Chords					
U_0U_1	-757	341.3	4182	670	0.69
U_1U_2	-1302	341.3	4182	670	0.82
U_2U_3	-1930	341.3	4182	670	0.97
U_3U_4	-2668	341.3	4182	670	1.14
U_4U_5	-3423	341.3	4182	670	1.33
U_5U_6	-3008	198.0	4341	670	0.98
U_6U_7	-2704	198.0	4341	670	0.92

Table 3/ Measured Strains (μs) on Stringers for Truck Longitudinal Position 2

Load Level	Transverse Position	Stringers 1			2		3		4		5		
		T	M	B	T	B	T	B	T	B	T	M	B
1	Line 4	-10	6	24	-132	135	-52	138	-115	91	-22	10	57
2		-8	10	31	-157	157	-83	198	-127	103	-3	9	37
3		-9	25	60	-224	247	-115	241	-186	155	-29	4	98
4		-23	15	59	-277	284	-175	295	-233	187	-36	44	110
5		-22	29	86	-326	333	-209	340	-277	215	-41	29	130
1	Line 5	-8	10	31	-157	157	-83	198	-126	103	-2	9	37
2		-11	18	50	-207	213	-132	270	-173	136	-1	13	47
3		-6	36	79	-259	279	-190	345	-213	177	0	10	61
4		-17	31	84	-317	331	-261	427	-261	211	0	18	61
5		-24	42	111	-368	381	-324	491	-308	248	-2	11	74

T = Top

M = Middle

B = Bottom

Table 4/ Measured Strains (μs) On Floor Beams at Load Level 5

Floor Beam Location	Transverse Location	Guage Location	Truck Position	1	2	3	4	5	6
U_0	Line 4	T		1	6	4	0	-3	-4
		B		17	6	0	-3	-4	-4
U_1		T		-226	-154	-3	-1	0	0
		B		372	191	-2	3	4	5
U_2		T		-289	-374	-34	3	3	2
		B		390	471	32	1	-2	-2
U_3		T		-44	-104	-319	-7	-9	-11
		B		76	200	390	3	-5	-6
U_4		T		2	1	-20	10	7	6
		B		3	7	38	-10	0	4
U_5		T		-1	-6	-13	-76	-5	-1
		B		-1	-2	6	72	3	5
	Σ Top Strains			-560	-631	-385	-71	-7	-8
	Σ Bottom Strains			857	873	466	66	0	0
U_0	Line 5	T		0	7	5	0	-6	-7
		B		20	3	-1	-3	-3	-3
U_1		T		-363	-209	1	7	6	6
		B		518	241	0	4	7	6
U_2		T		-398	-491	-40	-1	-3	-4
		B		518	610	32	0	-1	-3
U_3		T		-23	-134	-439	-8	-13	-15
		B		103	262	527	2	-4	-7
U_4		T		2	-1	-53	9	5	2
		B		6	9	72	7	3	6
U_5		T		-15	-15	-21	-106	-13	-7
		B		2	0	10	123	2	2
	Σ Top Strains			-797	-843	-505	-99	-24	-25
	Σ Bottom Strains			1167	1125	640	108	1	1

Table 5(a)/ Measured Strains (μs) On Floor Beams @ U_0 at Various Truck Positions

Load Level	Transverse Position	Guage Location	Truck Position 1	2	3	4	5	6
1	Line 4	T	0	4	2	0	0	0
		B	6	0	-3	-6	-7	-7
2		T	2	5	3	1	-1	-2
		B	10	3	-1	-4	-3	-3
3		T	1	5	4	0	-1	1
		B	23	12	7	5	3	2
4		T	-2	2	3	-3	-6	-7
		B	17	7	2	-1	-1	0
5		T	0	6	4	-1	-3	-4
		B	17	6	0	-3	-4	-4
1	Line 5	T	2	5	2	1	1	0
		B	7	1	0	-2	-2	-1
2		T	2	5	4	0	0	-2
		B	9	1	-2	-3	-4	-3
3		T	-5	3	0	-4	-8	-8
		B	19	7	4	1	1	1
4		T	-5	2	2	-7	-10	-9
		B	20	5	3	0	0	0
5		T	0	7	5	-3	-6	-7
		B	20	3	-1	0	-3	-3

Table 5(b)/ Measured Strains (μs) On Floor Beams @ U_1 at Various Truck Positions

Load Level	Transverse Position	Guage Location	Truck Position 1	2	3	4	5	6
1	Line 4	T	-67	-52	-7	-6	-4	-4
		B	155	80	-3	-2	-3	-3
2		T	-93	-72	0	1	3	0
		B	204	107	0	2	0	3
3		T	-137	-89	7	5	13	9
		B	274	146	8	10	11	10
4		T	-166	-108	2	21	17	11
		B	323	160	16	6	7	8
5		T	-227	-154	-2	-1	1	-1
		B	372	191	-2	3	4	5
1	Line 5	T	-122	-80	-6	-4	-2	-3
		B	218	104	1	3	5	5
2		T	-176	-113	-2	-3	0	-3
		B	287	138	-3	0	2	2
3		T	-239	-135	4	10	4	4
		B	372	175	4	6	7	8
4		T	-325	-171	0	6	1	-3
		B	466	215	4	8	8	9
5		T	-363	-209	1	7	6	6
		B	513	241	0	4	7	6

Table 5(c)/ Measured Strains (μs) On Floor Beams @ U_2 at Various Truck Positions

Load Level	Transverse Position	Guage Location	Truck Position 1	2	3	4	5	6
1	Line 4	T	-134	-156	-14	6	5	6
		B	112	216	10	0	-12	-12
2		T	-166	-203	-20	4	3	3
		B	242	280	18	-1	-4	-4
3		T	-215	-264	-24	1	3	0
		B	303	357	29	5	2	3
4		T	-264	-334	-29	0	-2	-3
		B	356	421	28	2	-1	0
5		T	-289	-374	-34	3	3	2
		B	390	471	33	1	2	-2
1	Line 5	T	-178	-207	-16	-3	5	4
		B	257	283	15	-3	-3	-4
2		T	-237	-286	-20	-5	6	3
		B	326	369	14	4	-7	7
3		T	-298	-358	-31	1	0	0
		B	394	455	27	1	-1	-2
4		T	-264	-334	-29	0	-2	-3
		B	357	421	28	2	-1	0
5		T	-398	-492	-40	-1	-3	-4
		B	518	609	32	0	-1	-3

Table 5(d)/ Measured Strains (μs) On Floor Beams @ U_3 at Various Truck Positions

Load Level	Transverse Position	Guage Location	Truck Position 1	2	3	4	5	6
1	Line 4	T	-21	-57	-109	0	0	0
		B	48	104	160	-4	-8	-8
2		T	-23	-79	-159	-2	-5	-7
		B	55	128	213	-1	-5	6
3		T	-33	-103	-209	-5	0	-2
		B	66	161	275	5	-7	-7
4		T	-48	-108	-273	-6	-10	-11
		B	79	194	338	8	1	1
5		T	-44	-104	-319	-7	-9	-11
		B	76	200	390	3	5	-6
1	Line 5	T	-35	-94	-161	-8	-7	-10
		B	70	140	221	1	0	-1
2		T	-42	-111	-239	-5	-6	-8
		B	77	171	303	0	-4	-4
3		T	-29	-111	-310	-8	-12	14
		B	89	213	390	6	2	1
4		T	-26	-130	-390	-11	-15	-15
		B	101	244	466	9	3	3
5		T	-23	-134	-440	-8	-13	-15
		B	103	262	527	2	4	-7

Table 5(e)/ Measured Strains (μs) On Floor Beams @ U_4 at Various Truck Positions

Load Level	Truck Transverse Position	Guage Location	Truck Position 1	2	3	4	5	6
1	Line 4	T	2	3	-9	5	4	5
		B	0	2	16	7	-5	-3
2		T	3	2	-11	7	5	5
		B	1	2	22	-6	0	1
3		T	2	1	-19	5	5	4
		B	11	16	35	0	7	9
4		T	-1	-4	-26	3	-1	-1
		B	3	8	34	-9	0	4
5		T	2	0	-21	10	7	6
		B	3	7	38	-10	0	4
1	Line 5	T	3	3	-22	1	3	1
		B	2	6	34	-4	1	3
2		T	3	1	41	7	7	5
		B	0	5	-32	-7	-2	1
3		T	0	0	-42	7	6	5
		B	9	14	55	-3	4	8
4		T	-3	-4	-56	3	0	1
		B	4	9	66	-7	2	6
5		T	2	9	-53	10	5	2
		B	6	-1	72	7	3	6

Table 5(f)/ Measured Strains (μs) On Floor Beams @ U_5 at Various Truck Positions

Load Level	Truck Transverse Position	Guage Location	Truck Position 1	2	3	4	5	6
1	Line 4	T	-4	-4	8	-15	-1	0
		B	0	-1	6	27	-2	1
2		T	2	-4	7	-29	-5	-5
		B	-1	-2	4	38	0	0
3		T	-3	-8	7	42	-5	-4
		B	3	3	10	55	5	5
4		T	-11	-11	13	61	-3	1
		B	3	0	7	68	2	5
5		T	-1	-6	13	-76	-5	-1
		B	-1	-2	6	72	3	5
1	Line 5	T	0	-2	12	-36	0	-1
		B	0	-1	7	46	2	2
2		T	-11	-14	10	-69	-4	0
		B	-3	-5	4	62	-1	-6
3		T	-13	-14	8	-73	-5	5
		B	2	2	10	82	3	-7
4		T	-9	-11	17	-96	-9	-3
		B	1	0	11	98	2	3
5		T	-15	-15	21	-106	-13	-7
		B	2	0	10	112	2	2

Table 6(a)/ Measured Strains (μs) or Truss Members for Level 4 Truck Loads

Member	Guage Position	Line 4						Line 5					
		1*	2	3	4	5	6	1	2	3	4	5	6
U_0U_1	T	68	87	76	0	-41	-47	73	92	66	-8	-43	-41
	B	15	-12	16	-3	-18	-19	18	3	10	-8	-18	-13
U_1U_2	T	-13	-36	11	14	7	6	11	0	9	10	4	4
	M	49	44	13	3	-1	7	32	18	8	7	-10	3
	B	89	110	-4	-14	-25	-26	52	61	-7	-18	-31	-29
U_3U_4	T	-17	-26	-35	-11	11	14	-21	-26	-37	-17	10	20
	B	-13	-11	17	-36	-10	-6	-7	-4	-8	-41	-8	5
U_4U_5	T	0	0	0	0	0	0	0	0	0	0	0	0
	B	-10	-12	49	-51	-36	-24	-10	-10	29	-49	-36	-23
U_7U_8	T	-1	-1	-6	-38	-36	-6	-4	-6	-8	-12	-33	-10
	B	-1	-1	1	-34	-65	-3	-4	0	-1	4	-62	-70
L_0L_1	T	-12	-17	-50	-96	-114	-117	-6	-11	-41	-87	-109	-113
	B	-52	-64	-89	-106	-103	-95	-38	-50	-74	-89	-88	-80
L_4L_5	T	18	23	10	-101	-156	-166	-23	26	20	-81	-143	-155
	B	24	33	68	-87	-200	-218	-22	30	61	-85	-192	-210
L_5L_6	T	14	18	20	-68	-111	-125	18	21	25	-50	-97	-113
	B	14	19	45	-7	-218	-250	14	17	43	-6	-196	-234
L_7L_8	T	-10	-13	-33	-123	-244	-263	0	-5	-27	-108	-210	-242
	B	-20	-22	-21	44	44	-21	-22	-25	-19	37	36	-16
L_0U_0		-160	-143	-71	31	74	86	-141	-132	-60	34	77	87
		-199	-167	-78	34	80	93	-181	-159	-70	36	84	97
L_1U_1		-328	-255	-110	7	59	74	-313	-251	-104	4	58	77
		-284	-289	-157	14	91	110	-233	-244	-143	15	95	118
L_4U_4		33	27	-200	-182	-43	-7	31	25	-161	-157	-32	3
		40	48	-107	-181	-56	-18	40	49	-51	-151	-39	-4
L_5U_4		73	94	70	-370	-174	-114	-69	90	70	-327	-150	-100
		73	93	107	-265	-174	-115	73	92	118	-174	-142	-95
U_0L_1		350	317	136	-71	-170	-183	314	285	-118	-80	-170	-180
		358	315	127	-80	-178	-191	316	281	-106	-94	-184	-193
U_4L_5		-72	-93	-82	319	77	0	-70	-91	-85	268	57	-7
		-65	-83	-24	324	54	-24	-60	-77	-28	270	32	-33
U_7L_8		-120	-156	-303	-500	-156	156	-109	-147	-287	-461	-159	118
		-112	-141	-243	-287	-77	285	-99	-129	-227	-256	70	250

* Truck longitudinal position (Typ)

Table 6(b)/ Measured Strains (μs) or Truss Members for Level 5 Truck Loads

Member	Guage Position	Line 4						Line 5					
		1*	2	3	4	5	6	1	2	3	4	5	6
U_0U_1	T	72	98	92	9	-43	-40	88	104	88	2	-42	-49
	B	8	-10	20	8	-16	-9	31	7	28	6	-13	-14
U_1U_2	T	-17	-41	14	14	9	6	10	-1	15	13	8	3
	M	16	29	0	0	-28	-8	34	11	-11	-5	-8	-28
	B	106	130	-5	-15	-28	-29	70	74	-4	-17	-30	-36
U_3U_4	T	-18	-22	-37	-2	22	34	-12	-24	-28	-4	25	29
	B	-8	-5	18	-28	0	12	0	-3	8	-27	25	29
U_4U_5	T	0	0	0	0	0	0	0	0	0	0	0	0
	B	-6	-7	53	-50	-34	-18	-1	-4	41	-49	-33	-18
U_7U_8	T	-7	-4	-10	-46	-42	-7	3	-2	-6	-15	-39	-14
	B	4	4	4	42	-70	-78	7	7	6	16	-61	-72
L_0L_1	T	-15	-19	-54	-106	-128	-131	-4	-10	-44	-96	-120	-125
	B	-64	-77	-107	-128	-125	-118	-61	-74	-104	-124	-122	-116
L_4L_5	T	20	26	13	-111	-174	-188	24	29	20	-97	-163	-180
	B	27	38	79	-95	-223	-247	26	35	71	-98	-216	-242
L_5L_6	T	11	15	18	-81	-131	-148	9	12	15	-72	-121	-141
	B	14	20	49	-5	-243	-283	12	17	43	-12	-223	-269
L_7L_8	T	-9	-13	-38	-135	-273	-299	1	-5	-30	-122	-247	-279
	B	-23	-25	-22	51	53	-15	-27	-27	-25	40	44	-18
L_0U_0		-186	-169	-82	39	86	104	-160	-148	-58	49	93	99
		-234	-200	-92	42	93	114	-205	-180	-70	50	100	108
L_1U_1		-378	-296	-124	16	71	95	-351	-282	-104	20	75	89
		-332	-335	-183	19	102	132	-269	-284	-160	23	104	124
L_4U_4		35	33	-218	-203	-51	-8	38	31	-177	-176	-40	0
		43	54	-112	202	-65	-22	44	53	-58	-176	-55	-15
L_5U_5		82	106	91	-413	-196	-131	82	105	87	-373	-175	-115
		76	100	121	-304	-208	-145	70	91	121	-221	-186	-130
U_0L_1		393	360	154	-75	-188	-198	364	326	143	-85	-187	-209
		405	366	153	-77	-189	-197	384	338	148	-82	-183	-203
U_4L_5		-80	-102	-101	363	92	10	-74	-98	-95	320	82	1
		-75	-93	-39	368	64	-20	-67	-88	-36	316	48	-34
U_7L_8		-132	-173	-343	-567	-173	172	-127	-169	-331	-531	-187	146
		-122	-154	-274	-330	90	321	-108	-142	-256	-293	76	236

* Truck Longitudinal Position (Typ)

Table 7/ Comparison of Measured and Calculated Strains for Load Case Level 5, Line 4

Member	Guage Position	Calculated						Measured					
		1*	2	3	4	5	6	1	2	3	4	5	6
U_0U_1	T	-102	-89	-40	22	54	59	72	98	92	9	-43	-40
	B	-102	-89	-40	22	54	59	8	-10	20	8	-16	-9
U_1U_2	T	-274	-479	-123	39	121	136	-17	-41	14	14	9	6
	M	-189	-202	-123	39	121	136	16	29	0	0	-28	-8
	B	-73	177	-123	39	121	136	106	130	-5	-15	-28	-29
U_3U_4	T	-219	-287	-563	-36	283	348	-18	-22	-37	-2	22	34
	B	-219	-264	-288	-36	283	348	-8	-5	18	-28	0	12
U_4U_5	T	-207	-263	-577	-278	317	449	0	0	0	0	0	0
	B	-207	-263	-302	-278	317	449	-6	-7	50	-50	-34	-18
L_0L_1	T	-38	-48	-85	-131	-151	-148	-15	-19	-54	-106	-128	-131
	B	-38	-48	-85	-131	-151	-148	-64	-77	-107	-128	-125	-118
L_4L_5	T	42	53	78	-114	-247	-268	20	26	13	-111	-174	-188
	B	42	53	78	-114	-247	-268	27	38	79	-95	-223	-247
L_5L_6	T	36	45	79	-30	-256	-300	11	15	18	-81	-131	-148
	B	36	45	79	-30	-256	-300	14	20	49	-5	-243	-283
L_7L_8	T	-3	-4	-7	-23	-165	-268	-9	-13	-38	-135	-273	-299
	B	-3	-4	-7	-23	-165	-268	-23	-25	-22	51	53	-15
L_0U_0		-265	-229	-102	60	142	155	-186	-169	-82	39	86	104
		-265	-229	-102	60	142	155	-234	-200	-92	42	93	114
L_1U_1		-434	-384	-206	21	138	161	-378	-296	-124	16	71	95
		-434	-384	-206	21	138	161	-332	-335	-183	19	102	132
L_4U_4		15	9	-318	-242	30	95	35	33	-218	-203	-51	-8
		15	9	-318	-242	30	95	43	54	-112	202	-65	-22
L_5U_5		49	-28	36	-439	-131	0	82	106	91	-413	-196	-131
		49	-28	36	-439	-131	0	76	100	121	-304	-208	-145
U_0L_1		553	479	215	-123	-294	-322	393	360	154	-75	-188	-198
		553	479	215	-123	-294	-322	405	366	153	-77	-189	-197
U_4L_5		-36	-46	20	582	-76	-235	-80	-102	-101	363	92	10
		-36	-46	20	582	-76	-235	-75	-93	-39	368	64	-20
U_7L_8		-253	-321	-563	-786	81	832	-132	-173	-343	-567	-173	172
		-253	-321	-563	-786	81	832	-122	-154	-274	-330	90	321

* Truck Longitudinal Position (Typ)

Figure 1/ A View of Keewatin Channel Bridge

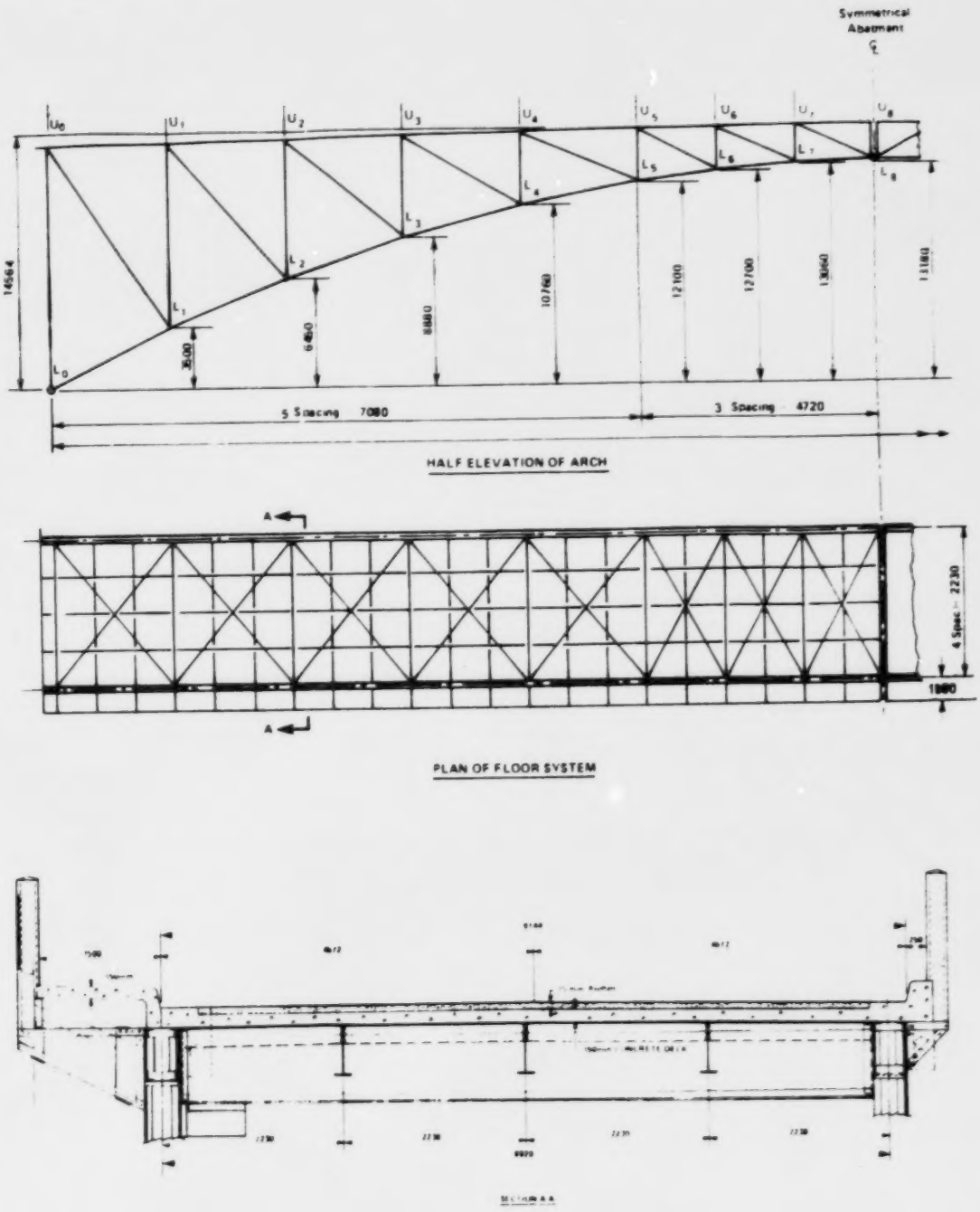


Figure 2(a)/ Bridge Details

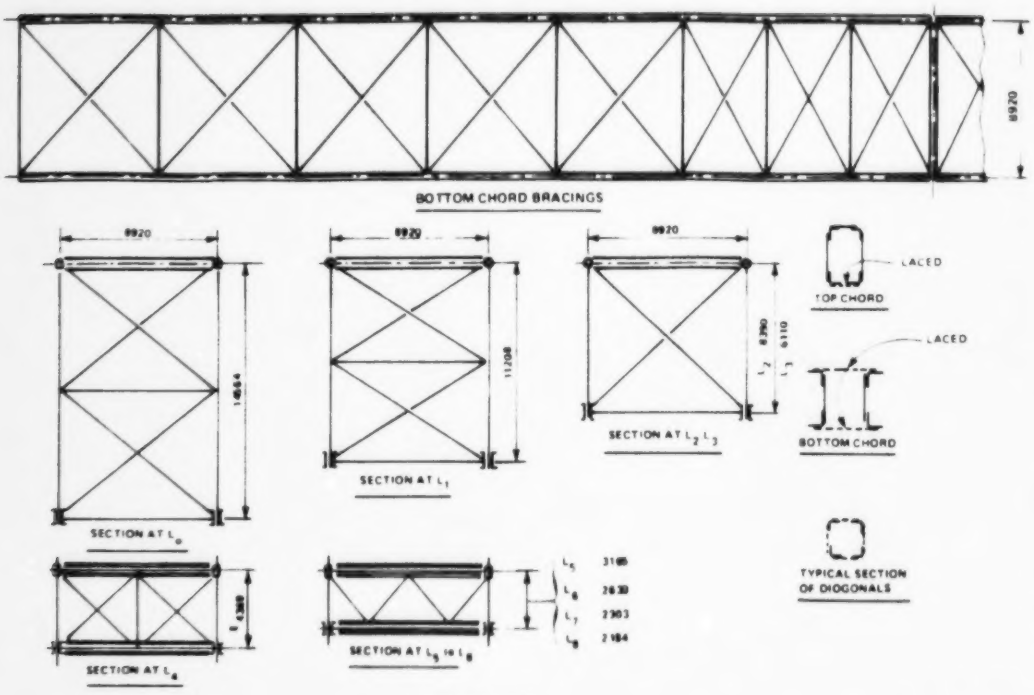
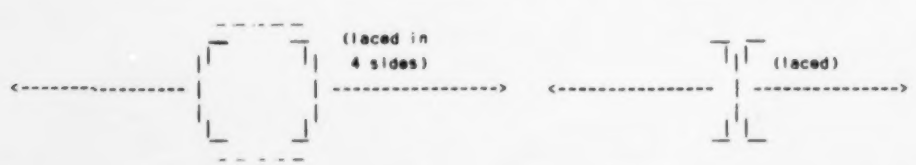


TABLE OF MATERIAL*

Top Chord:	U_0-U_1	U_1-U_2	U_2-U_3	U_3-U_4	U_4-U_5	U_5-U_6	U_6-U_7	U_7-U_8
Material:	<---------- 4L^S $3\frac{1}{2}\times3\frac{1}{2}\times\frac{3}{8}$", 2PLS $24\times\frac{3}{8}$", 1PL $14\times\frac{3}{8}$" ---------->							
Bottom Chord:	L_0-L_1	L_1-L_2	L_2-L_3	L_3-L_4	L_4-L_5	L_5-L_6	L_6-L_7	L_7-L_8
Material:	2PLS $16\times\frac{3}{4}$"	2PLS $16\times\frac{11}{16}$	2PLS $16\times\frac{5}{8}$	2PLS $16\times\frac{5}{8}$	2PLS $16\times\frac{5}{8}$	2PLS $16\times\frac{5}{8}$	2PLS $16\times\frac{1}{2}$	2PLS $16\times\frac{7}{8}$
	<---------- 2PLS 24 x 1 ---------->							
	<---------- 4L^S 6 x 4 x $\frac{3}{4}$ ---------->							
Diagonals:	U_0-L_1	U_1-L_2	U_2-L_3	U_3-L_4	U_4-U_5	U_5-L_6	U_6-L_7	U_7-L_8
Material:	4L^S $3\frac{1}{2}\times3\frac{1}{2}\times\frac{7}{16}$	4L^S $3\frac{1}{2}\times3\frac{1}{2}\times\frac{1}{2}$	<------ 4L^S $3\frac{1}{2}\times3\frac{1}{2}\times\frac{9}{16}$ ------>			<-- 4L^S $3\frac{1}{2}\times3\frac{1}{2}\times\frac{3}{8}$ -->		4L^S $3\frac{1}{2}\times3\frac{1}{2}\times\frac{1}{2}$
Verticals:	U_0L_0	U_1L_1	U_2L_2	U_3L_3	U_4L_4	U_5L_5	U_6L_6	U_7L_7 U_8L_8
Material:	4L^S $4\times4\times\frac{11}{16}$	4L^S $4\times4\times\frac{9}{16}$	4L^S $4\times4\times\frac{1}{2}$	4L^S $4\times4\times\frac{7}{16}$	4L^S $4\times4\times\frac{3}{8}$	<---------- 4L^S $3\frac{1}{2}\times3\frac{1}{2}\times\frac{3}{8}$ ----------		



* Material sizes given in Imperial units.

Figure 2(b)/ Bridge Details

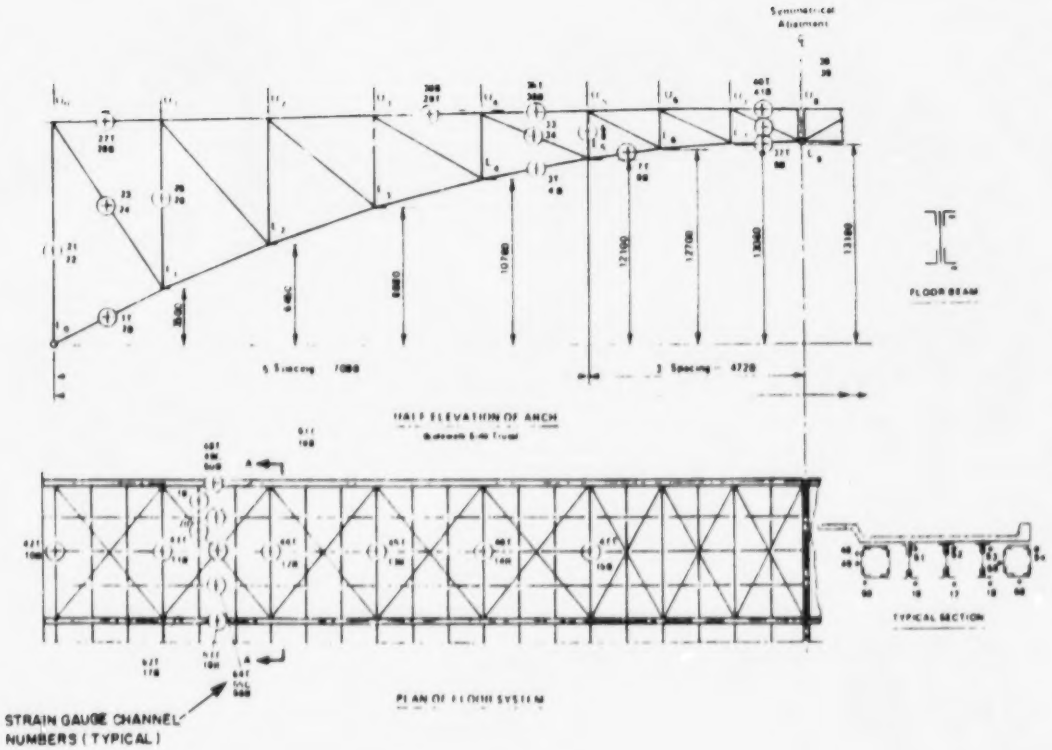
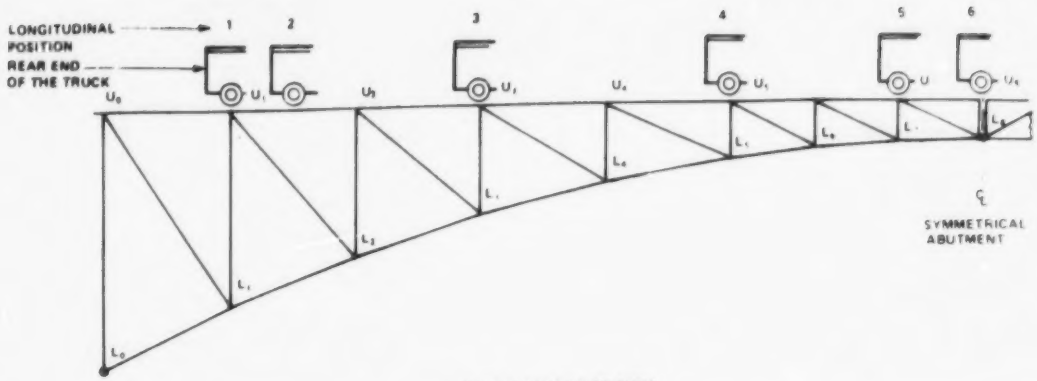
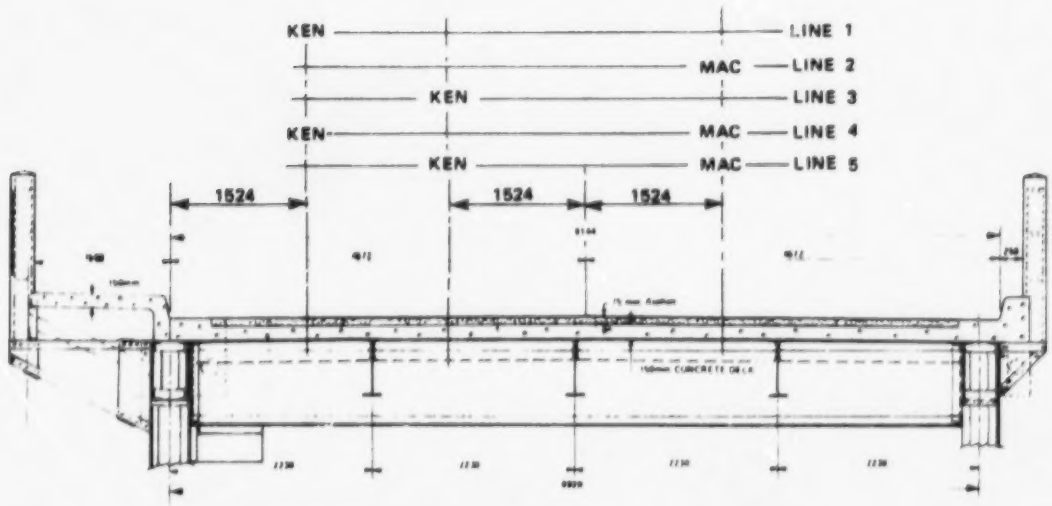


Figure 3(a)/ Instrumentation Details



HALF ELEVATION OF ARCH



TRUCK TRANSVERSE POSITION

AXLE WEIGHTS OF TEST VEHICLES

	Load Level No.	Weight of Axle No 1	2	3	4	5	Total Vehicle Weight (KN)
KEN	1	47.7	92.7	92.7	105.2	105.2	443.6
	2	49.5	119.4	119.4	136.9	136.9	554.6
	3	51.7	138.7	138.7	168.9	168.9	667.1
	4	53.5	161.9	161.9	201.1	201.1	779.4
	5	56.2	189.5	189.5	232.3	232.3	891.8
MAC	1	43.6	90.3	90.3	104.6	104.6	433.4
	2	44.6	113.2	113.2	137.3	137.3	545.7
	3	45.9	136.4	136.4	169.8	169.8	658.1
	4	46.8	159.4	159.4	202.6	202.6	770.9
	5	47.7	204.9	204.9	234.3	234.3	881.5

Figure 3(b)/ Truck Positions and Truck Axle Loads

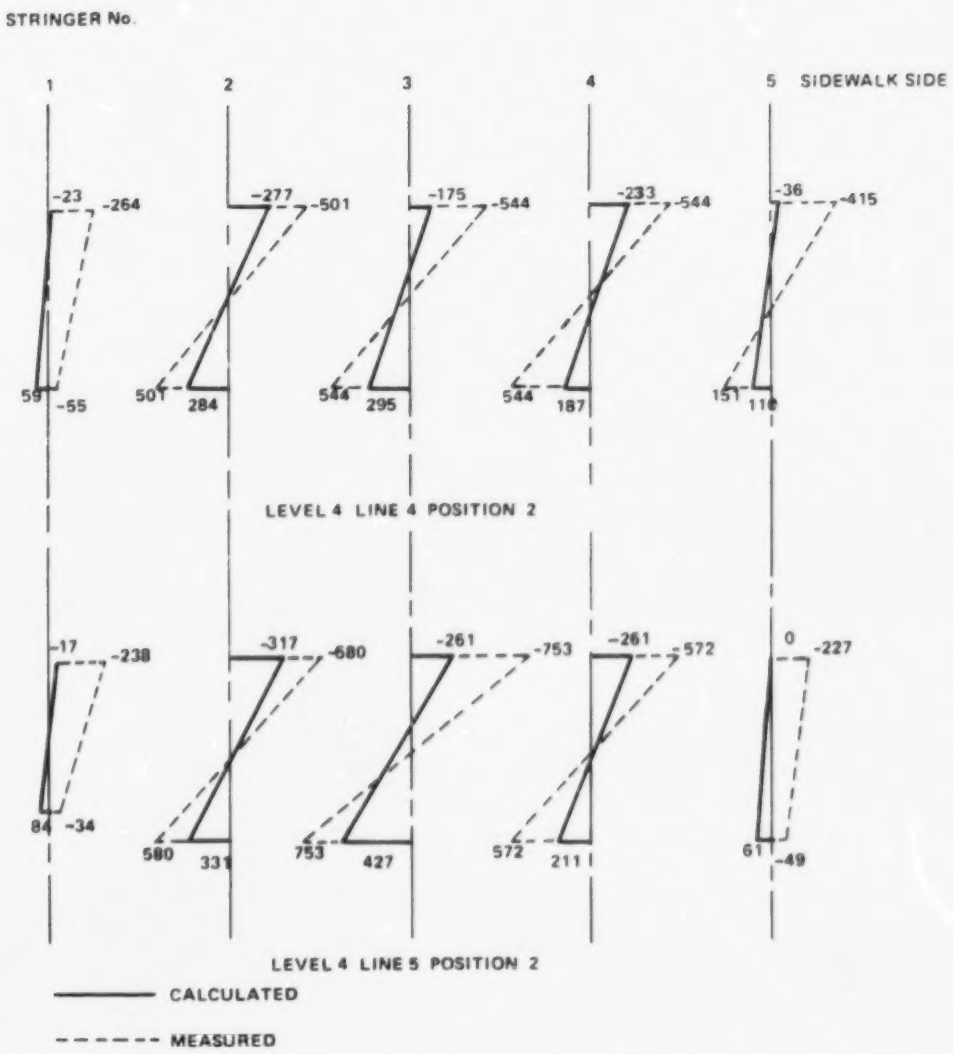
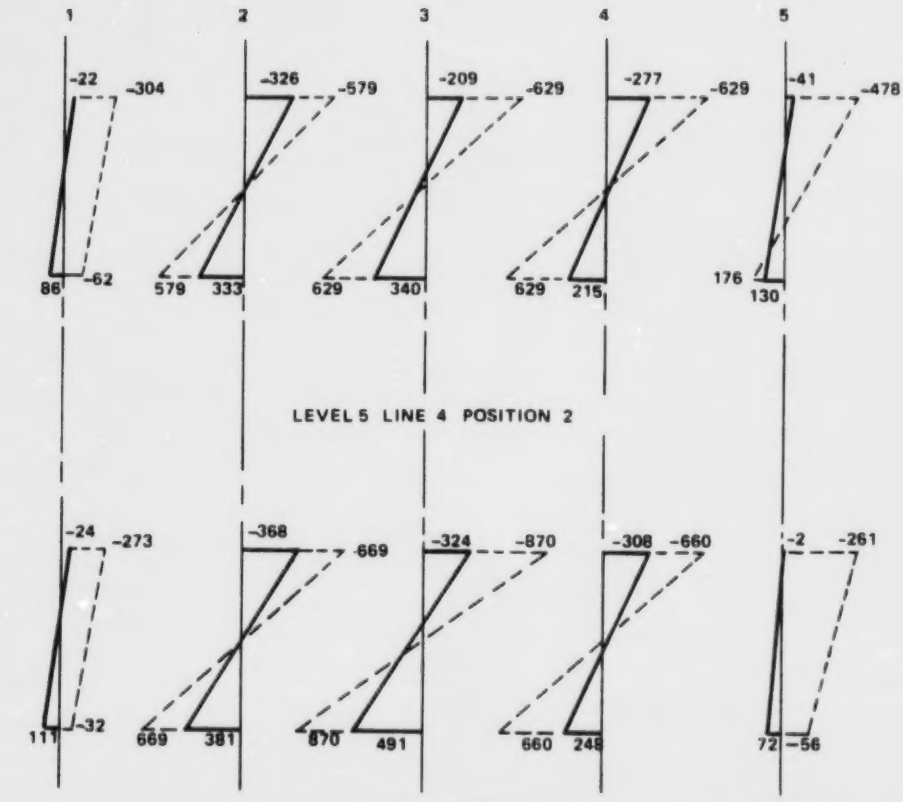


Figure 4(a)/ Comparison of Measured and Calculated Strains on Stringers



NOTE: Stringers No. 1 and 5 are truss top chords also acting as stringers in the floor system.

Figure 4(b)/ Comparison of Measured and Calculated Strains on the Stringers

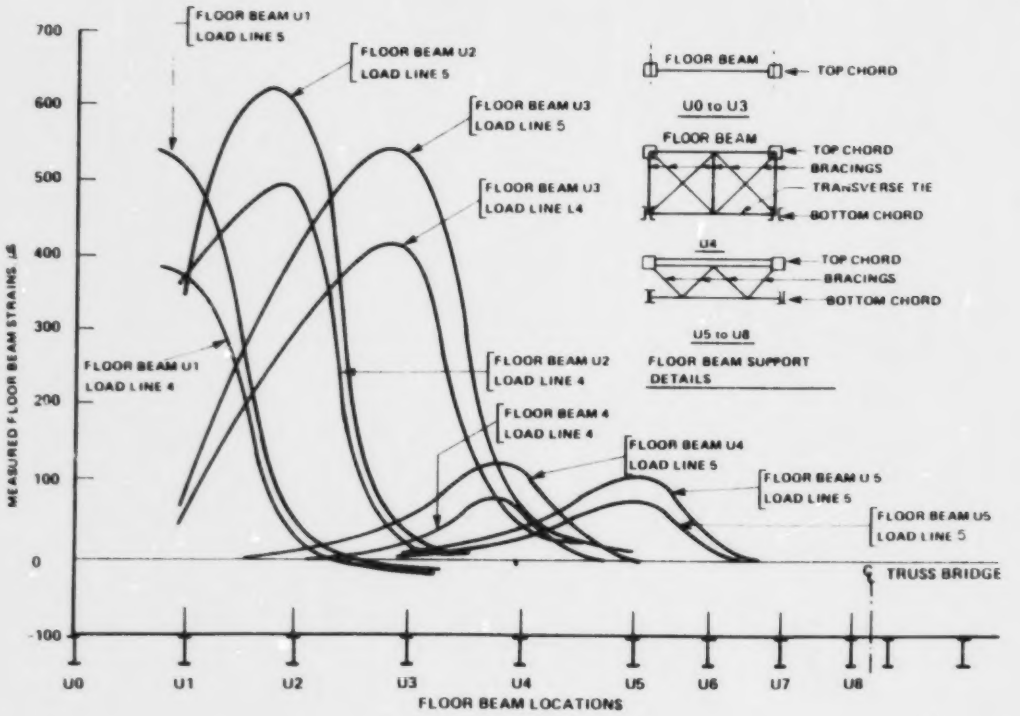


Figure 5/ Measured Floor Beam Strains Related to Truck Positions, Load Level 5

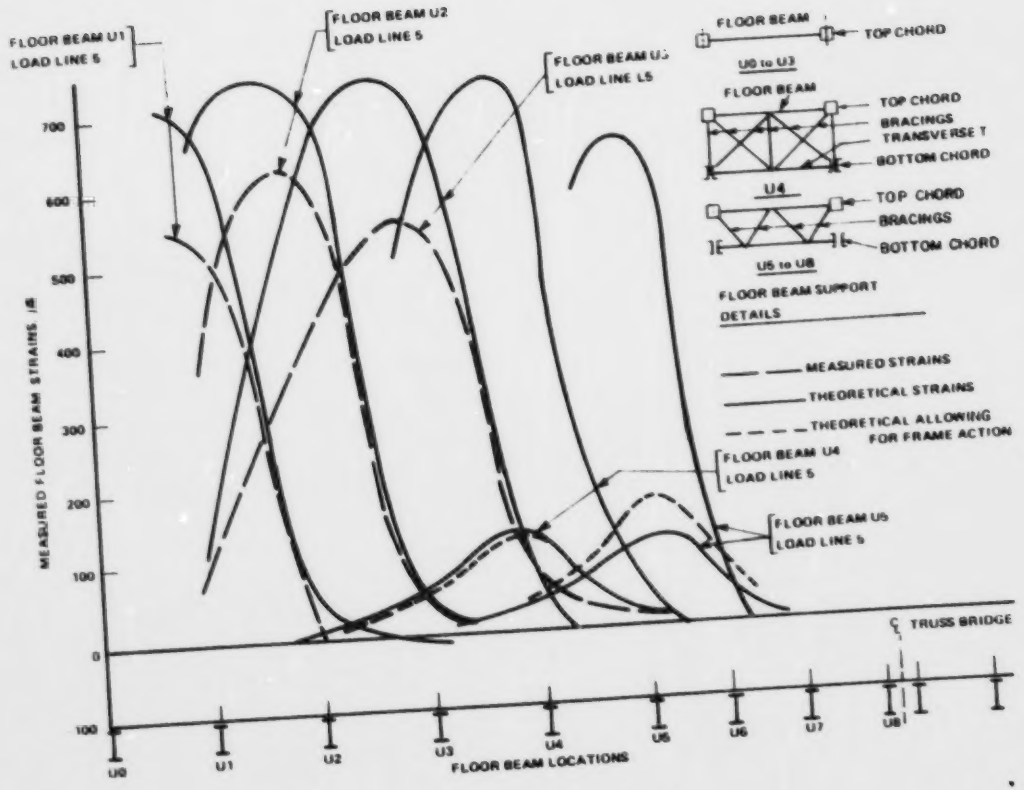


Figure 6/Measured and Theoretical Floor Beam Strains Related to Truck Positions